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Development of Overarm Throwing Technique Reflects Throwing Ability during Childhood

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ABSTRACT. Background: It is important to acquire fundamental movement skills during childhood. Throwing is a representative manipulative skill required for various intrinsic factors. However, the relationship between intrinsic factors and throwing ability in childhood is unclear. The purpose of this study was to investigate intrinsic factors related to the ball throwing distance of Japanese elementary school children. Methods: Japanese elementary school children from grades 1-6 (aged 6-12 years; n=112) participated in this study. The main outcome was throwing ability, which was measured as the ball throwing distance. We measured five general anthropometric parameters, seven physical fitness parameters, and the Roberton's developmental sequence for all subjects. The relationships between the throwing ability and the 13 parameters were analysed. Results: The Roberton's developmental sequence was the best predictor of ball throwing distance ($r=0.80$, $p\leq 0.01$). The best multiple regression model, which included sex, handgrip strength, shuttle run test, and the Roberton's developmental sequence, accounted for 81% of the total variance. Conclusions: The development of correct throwing technique reflects throwing abilities in childhood. In addition to the throwing sequence, enhancement of grip strength and aerobic capacity are also required for children's throwing ability.

Key words: Fundamental movement skill, Developmental kinesiology, Physical fitness

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Fundamental movement skills help children control their bodies, manipulate their environment, and form complex skills and movement patterns for sports and other recreational activities[1)]. Fundamental movement skills are classified into three motor skill groups, namely locomotors, stability, and manipulative skills[2)]. These skills typically emerge between ages 2 to 8 or 9 years, which is a landmarked period of motor development[3)]. Characteristics of early overarm throwing, especially those of children under 3 years, tend to be restricted to arm action alone[4)]. The children do not step into the throw or use much trunk action. Advanced thrower carried out the movement of the body segments sequentially, progressively adding the contribution of each part to the force of the throw. Researchers have revealed that many children demonstrate mature patterns of motor skill development by the age of 10 years[5)].

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An important part of a comprehensive physical education program is instruction about fundamental movement skills. Evaluating individual factors that constitute movement is necessary for proper teaching. Physical therapists and physical education teachers attempt to develop optimal training programs for throwing children to enjoy the play, improve performance, and facilitate motor skill through instruction and rehabilitation[6)]. Throwing is considered as one of the most important manipulative skills. For example, advanced forms of the overhand throw include a baseball pitch, cricket pitch, javelin throw, tennis serve, and volleyball spike. The presence of a full or partial overhand throw can be detected in sport-specific movement skill patterns.

Throwing attributes required for high-level activities include muscular strength, power, endurance, flexibility, balance, agility and proper developmental movement patterns. Depending on the type of throw, the achievement of adequate ball throwing distance is necessary to properly execute a throw, while accuracy is always a demand. An-

Table 1. Subject characteristics.

Grade	sex	n	Body Height (cm)		Body Weight (kg)		BMI (kg/m²)	
			Mean	SD	Mean	SD	Mean	SD
1st	Boys	17	115.9	4.8	21.1	3.1	15.6	1.4
	Girls	6	111.3	3.1	18.0	2.0	14.5	1.1
2nd	Boys	6	124.9	5.0	24.2	3.5	15.4	1.4
	Girls	9	121.1	3.7	22.9	3.3	15.6	1.6
3rd	Boys	9	128.5	3.8	25.9	1.6	15.7	1.0
	Girls	7	124.1	4.1	23.3	2.0	15.1	0.5
4th	Boys	5	130.5	6.9	27.6	5.8	16.0	1.9
	Girls	10	132.7	6.2	29.2	4.2	16.5	1.4
5th	Boys	11	138.0	6.8	36.2	7.8	18.8	2.4
	Girls	13	137.5	3.8	30.3	3.8	16.0	1.7
6th	Boys	9	144.9	5.1	36.3	5.3	17.2	2.0
	Girls	10	141.4	6.5	35.3	10.5	17.4	3.9

thropometric and demographic characteristics should be considered for predicting ball throwing ability. Significant positive correlations have been shown between ball throwing ability and demographic characteristics parameters in previous studies[7-9]. Although demographic characteristics parameters seem to be related to ball throwing ability in previous studies, these studies had a low predictability level due to the inclusion of matured adult subjects. Muscle strength is considered an important parameter for successful objective movements performed with maximum effort[7]. Therefore, strength and power tests are related to ball throwing ability. Total body movement during throwing requires various physical fitness parameters. It has been determined that total body conditions, such as flexibility and endurance, may also be associated with ball throwing[10,11]. Appropriate technique also affects ball throwing in childhood. Children with immature musculoskeletal systems compensate for muscle strength by learning a combination of various movements. Briefly, children improve movement quality by increasing coordination of body parts and neuromuscular function rather than muscle strength. In a previous research study, multiple regression analysis was used to investigate the changing relationship between qualitative movement descriptions of the overarm throw and throwing outcome[12]. It is necessary to investigate correct developmental movement when determining the factors affecting ball throwing ability.

According to the best of our knowledge, no studies have been conducted using combined predictive models of anthropometric and demographic characteristics, physical fitness, and developmental parameters. A few previous researchers have investigated the influence of anthropometric characteristics and physical fitness parameters on ball throwing ability[7-9]. These authors confirmed that physical fitness had a greater influence on ball throwing ability than anthropometric characteristics parameters, especially when considering muscle strength and power. These previous studies of adults with mature throwing motion have been done, but research about throwing abilities in children during the growth period is currently limited. We hypothesize that the significant contribution of developmental factors than physical fitness parameter in the childhood, it is expected that musculoskeletal effect is greater when it comes to adolescence.The purpose of this study was to examine intrinsic factors related to the ball throwing distance in Japanese elementary school children.

Methods

Participants and methods

Japanese elementary school children in grades 1-6 (n= 112; 57 boys and 55 girls; aged 6-12 years) participated in this study. Children who did not have a history of a musculoskeletal disorder in the upper and lower extremities during the last 3 months prior to starting the study. Descriptive statistics of subject characteristics were shown in Table 1. Children and their parents were informed about this study and written consent from each child's parents was obtained. The study conformed to the declaration of Helsinki, and was approved by the Health Science University Ethics Committee.

The main outcome of this study was throwing ability, which was measured as the ball throwing distance. The ball throwing distance was defined as the distance a softball was thrown. Participants were asked to throw the softball using their dominant hand without moving their feet outside of a circle with a diameter of 2 m. The softball weighted 0.14 kg and had a perimeter of 0.27 m. The throwing distance was measured from the point where the ball lands to circular, and the distance was recorded from the edge of the circle to the landing point of the ball. The test was repeated twice and the measurement for the best throw was recorded.

We also measured anthropometric and demographic characteristics parameters, physical fitness parameters, and the Roberton's developmental sequence in participants. Anthropometric and demographic characteristics parameters included body height and weight measurements, which were measured with a stadiometer and a digital scale, respectively. Participants were dressed in lightweight clothing and were not wearing shoes at the time of body weight and height measurements. The body mass index was calculated as weight in kilograms divided by height in meters squared.

The principal goal of the physical fitness test was to evaluate overall body function, including muscle strength, power, speed, balance, flexibility, aerobic capacity, and body coordination. Handgrip strength was measured with an adjustable handgrip dynamometer (TK005; Takei Scientific Instruments, Tokyo, Japan). Handgrip strength was measured twice in the dominant hand. Participants were instructed to squeeze the handgrip as hard as possible with an outstretched arm. The best result for the dominant hand was used in the analysis.

The side-step test is an accepted measurement of agility, which is an aspect of coordination. The participants were asked to stand on a centre line facing the same direction (line interval=1 m). When the command "start" was given, they side-stepped (not a jump) to touch or crossover the line on the right, returned to the centre line, and then side-stepped to touch or cross the line on the left. This motion was repeated for 20 seconds and 1 point was provided for touching or crossing each line. This side-step test was conducted twice, and the best score was recorded.

The sit-up test was conducted to evaluate the strength of the trunk. The participants were asked to lie on their backs, with their hips and knees flexed and their arms crossed over their chests, and do as many sit-ups as possible during a period of 30 seconds. Only complete sit-ups (i. e., sit-ups where the forearms touched the thighs of the participants) were counted.

Flexibility of the back and lower extremity was determined with a sit-and-reach test. Participants were asked to sit on the floor with straightened legs and their feet against a Wells-type sit-and-reach box, and then reach forward with their arms as far as possible along a measuring tape placed across the box. The better of the two attempts (farthest distance reached) was included in the analysis.

The shuttle run test was used to measure aerobic capacity. During the test, participants continuously ran between two lines (20 m apart) to recorded beeps on a compact disc, and turned when signalled by the recorded beeps. During each minute, a beep sound indicated an increase in speed during which the beeps occurred closer together. If a participant did not reach the line in time for each beep, they had to run to the line, turn, and try to accelerate the pace within the next two beeps. The test was stopped when the child failed to reach the line (within 2 meters) for two consecutive ends. The number of the last line passed by the child when the test ended was recorded.

The 50 m sprint was used to measure speed. Participants were instructed to run in a straight line with the highest speed possible. The test was performed once and recorded to the nearest 0.1 s (HS-3C-8AJH stopwatch; CASIO, Tokyo, Japan).

The standing long jump was used to measure muscular power. A non-slip gymnasium floor with a clearly marked line for take-off was used. The distance of the participant's jump, from the take-off line to the nearest point of contact (back of the heels) during landing was measured using a tape measure. The standing long jump was performed twice, and the best recorded distance was used for analysis.

Throwing technique development was evaluated for the overarm throw using the Roberton's developmental sequence[12-15]. The model component analysis, presented by Roberton and Halverson, involves the following five components for overarm throw: arm preparation backswing (four developmental steps), humerus action (three developmental steps), forearm action (three developmental steps), trunk action (three developmental steps), and foot action (four developmental steps). The steps for different body actions, which have been divided into segmental movement components, are shown in Table 2. The Roberton's developmental sequence score was obtained by summing the steps of each component and an accumulative score was used for data analysis. Two obserever were physical therapist and physical educator. The evaluation of developmental sequence score was carried out by two observers that showed a satisfactory inter-obserever agreement. They have 90% of agreement in scoring. The minimum and maximum total developmental sequence scores were 5 and 17 points, respectively. A sagittal view of the throwing sequence was obtained from a digital video recorder located 3 m away from the participant using a hi-speed digital camera (Gopro Hero3 black edition, Gopro Inc., California, USA). The digital video recorder equipped with the camera (resolution of 720 p) was used to record movement in a large, open field at 120 fps.

Statistical analyses

Pearson correlation coefficients were used to determine the relationship among the 13 independent variables. The 13 independent variables were: 1) five anthropometric and demographic characteristics parameters (i.e., grade, sex, body weight, body height, and body mass index); 2) seven physical fitness parameters (i.e., maximal isometric handgrip strength, side-step test, sit-up test, sit-and-reach test, shuttle run test, 50 m sprint, and standing long jump); and 3) the Roberton's developmental sequence. The dependent variable was the ball throwing distance. A multiple-regression analysis was carried out using a for-

Table 2. The Roberton's developmental sequence for the five throwing components

Compornent	Step 1 (1pt)	Step 2 (2pt)	Step 3 (3pt)	Step 4 (4pt)
Arm preparation backswing	No backswing	Elbow and humeral flexion	Circular Upward backswing	Circular Downward backswing
Humerus action	Humerus oblique	Humerus aligned but independent	Humerus lags	
Forearm action	No Forarm lag	Forarm lag	Delayed Forarm lag	
Trunk action	No trunk action	Upper trunk rotaion or total trunk rotation	Differentiated rotation.	
Foot action	No step	Homolateral step	Short contralateral step	Long contralateral step (over a distance of more than half the body height)

The Roberton's developmental sequence score is obtained by summing the steps of each component.
All components are described in previous studies [12-15].
Minimum score=5, Maximam score=17, pt=point

ward stepwise procedure with significance accepted at the $p<0.05$ level. These analyses determine the effect of anthropometric and demographic characteristics parameter, physical fitness parameter, and developmental parameters on the ball throwing distance. All analyses were performed with SPSS Advanced Models 16.0 for Windows (SPSS Japan, Inc., Tokyo, Japan).

Results

The mean values of all parameters and the correlations between the ball throwing distance and parameters are summarized in Table 3, 4, respectively. The mean ball throwing distance was 14.1 ± 8.2 m. Three of anthropometric and demographic characteristics parameters (grade, body height, and body weight) were correlated with the ball throwing distance ($p<0.01$). The r-values ranged from 0.57 (body weight) to 0.73 (grade). The physical fitness parameters, except for the sit-and-reach test, were also correlated with the ball throwing distance. Among all parameters, the Roberton's developmental sequence was the most highly correlated with the ball throwing distance ($r=0.80$, $p<0.01$).

We tested all the models that included parameters. The results from the best models are showed in Table 5 and classified into four categories: (1) anthropometric and demographic characteristics model, (2) physical fitness model, (3) developmental sequence model, and (4) all combined models. All models were significantly correlated with the ball throwing distance. Firstly, the anthropometric and demographic characteristics model, which included two demographic characteristics variables (grade and sex), accounted for 65% of the total variance. Secondly, the physical fitness model, which included handgrip strength and the shuttle run test, accounted for 74% of the total variance. Thirdly, the Roberton's developmental sequence model accounted for 64% of the total variance. Lastly, the anthropometric and demographic characteristics, physical fitness, and the Roberton's developmental sequence models were combined, and the most predictive parameters with correlation coefficients were retained ($p<0.01$). The combined best model included sex, handgrip strength, shuttle run test, and the Roberton's developmental sequence, accounted for 81% of the total variance.

Discussion

In this study, we investigated the effect of anthropometric and demographic characteristics, physical fitness, and developmental parameters on the ball throwing distance. Anthropometric and demographic characteristics parameters (i.e., grade, body height, and body weight) were correlated with the ball throwing distance. This positive correlation between body height and ball velocity was in accordance with previous studies involving male and female athletes[16]. Reasonably, an overall longer limb has a positive effect on ball release velocity. Mechanically, increased rotation of the forearm should cause a proportional increase in the force applied to the ball, and consequently increase the ball throwing distance. Other investigators have revealed that weight and especially height have a strong association with muscle strength in children[17]. Therefore, the ball throwing distance is increased with progressions in muscle strength and joint movement during growth. Anthropometrical development (i.e., measurements in age, height, weight, and fat-free body mass) markedly influences motor performance, including throwing ability, and accounts for 46-65% of the variation among motor performance measures[7]. In the present study, 65% of the variation can be described by the anthropometric parameter, and anthropometric development strongly affects the throwing distance.

The physical fitness model showed a higher rate of the

Table 3. The mean parameter values for children

	Boys (n=57)		Girls (n=55)		All (n=112)	
	Mean	SD	Mean	SD	Mean	SD
Ball throwing distance (m)	16.0	9.6	12.2	5.7	14.1	8.2
Grade	3.2	1.9	3.8	1.6	3.5	1.8
Body Height (m)	129.0	11.7	130.1	10.8	129.5	11.3
Body Weight (kg)	28.1	8.0	27.6	7.6	27.8	7.8
Body Mass Index (kg/m^3)	128.3	13.5	123.2	15.2	125.8	14.6
Handgrip strength (kg)	14.0	4.0	12.8	3.3	13.4	3.7
Sit up test (rep)	15.4	6.8	15.8	6.9	15.6	6.9
Sit to reach test (cm)	28.1	6.8	32.4	6.9	30.2	7.2
Side-step test (rep)	33.8	9.3	35.9	8.1	34.8	8.8
Shuttle run test (rep)	31.7	22.7	26.8	13.7	29.3	19.0
50 m sprint (s)	10.7	1.7	10.6	1.2	10.6	1.5
Standing long jump (cm)	128.8	28.7	127.8	22.0	128.3	25.6
Roberton's development sequence	13.0	2.9	12.7	2.2	12.8	2.6

SD: Standard diviation,

Table 4. Correlation matrix for ball throwing distance and independent variables

	Ball throw distance	Grade	Sex	Body Height	Body Weight	Body Mass Index	Hand-grip strength	Sit up test	Sit to reach test	Repeti-tive side steps	Shuttle run test	50 m sprint	Standing long jump
Grade	0.73**												
Sex	–0.23*	0.16											
Body Height (m)	0.69**	0.88**	0.05										
Body Weight (kg)	0.57**	0.72**	–0.03	0.87**									
Body Mass Index (kg/m^3)	0.27**	0.38**	–0.12	0.37**	0.47**								
Handgrip strength (kg)	0.76**	0.79**	–0.16	0.81**	0.76**	0.35**							
Sit up test (rep)	0.58**	0.66**	0.03	0.62**	0.47**	0.14	0.64**						
Sit to reach test (cm)	0.32**	0.49**	0.30**	0.51**	0.42**	0.27**	0.38**	0.44**					
Side-step test (rep)	0.72**	0.80**	0.12	0.73**	0.59**	0.21*	0.66**	0.64**	0.50**				
Shuttle run test (rep)	0.78**	0.70**	–0.13	0.59**	0.37**	–0.20*	0.59**	0.57**	0.33**	0.71**			
50 m sprint (s)	–0.68**	–0.67**	–0.02	–0.66**	–0.46**	0.26**	–0.63**	–0.65**	–0.47**	–0.73**	–0.69**		
Standing long jump (cm)	0.71**	0.75**	–0.02	0.72**	0.46**	0.25**	0.71**	0.64**	0.50**	0.70**	0.74**	–0.80**	
Roberton's development sequence	0.80**	0.81**	–0.07	0.72**	0.57**	0.27**	0.71**	0.60**	0.40**	0.75**	0.65**	–0.68**	0.67**

*: p<0.05, **: p<0.01

variation than the anthropometric and demographic characteristics model. In particular, the handgrip strength and shuttle run test were strongly associated with the ball throwing distance. The association between grip strength and throwing can be explained by evolution. According to a report about the relationship between human evolution and throwing motion, progressive thumb opposition and grip movement have led to throwing improvements[18]. A significant correlation between grip strength and throwing ability was also observed for other throwing activities, such as handball[10] and water polo[19]. To increase the throwing distance, it is also necessary to release the ball at an appropriate timing. Some insights into the central signals that control the fingers involved in throwing can be found in a pre-

Table 5. Multiple regression models for predicting the ball throwing distance

Models	Variable	Coefficients	β	R^2	p
Anthropometric demographic characteristics				0.65	p<0.01
	Constant	10.19			
	Grade	3.58	0.78		p<0.01
	Sex	–5.85	–0.36		p<0.01
Physical fitness				0.74	p<0.01
	Constant	–5.78			
	Grip strength	1.01	0.46		p<0.01
	Shuttle run test	0.22	0.50		p<0.01
Developmental sequence				0.64	p<0.01
	Constant	–17.67			
	Roberton's Developmental sequence	2.47	0.80		p<0.01
All combined				0.81	p<0.01
	Constant	–9.76			
	Roberton's Developmental sequence	1.16	0.36		p<0.01
	Grip strength	0.58	0.26		p<0.01
	Shuttle run test	0.16	0.37		p<0.01
	Sex	–1.94	–0.12		p<0.01

vious study about handgrip strength during throwing. Handgrip strength provides two essential functions during throwing[20]. Firstly, the handgrip strength prevents the ball from flying out of the hand. Secondly, as the ball is released and rolls along the fingers, handgrip strength prevents back forces from the ball from producing excessive finger extension. Therefore, a fast throw has to be controlled by grip strength.

In this study, we revealed that the throwing distance was correlated with aerobic capacity.

Additionally it showed a high contribution in the best model for prediction of throwing ability. Okely, et al.[21] reported a relationship between aerobic capacity and fundamental movement skills (locomotors and manipulative) among adolescents. In another study, it was reported that fundamental movement skills were related to aerobic capacity, which was indirectly measured using the Multi-Stage Fitness Test[22]. Manipulative skills in childhood were associated with adolescent cardiorespiratory fitness, accounting for 26% of fitness variation. Children with good manipulative skills (i.e., throwing, kicking, and catching) are more likely to become physically fit adolescents. Manipulative skills are often associated with moderate and/or vigorous intensity physical activities. Children who are proficient at performing these manipulative skills may participate in more activities that will likely increase their fitness levels.

The Roberton's developmental sequence is an obvious factor for predicting the throwing ability in childhood. Using a multiple regression analysis, the predictability level increased from 64% with one factor (i.e., the Roberton's developmental sequence) to 81% with a four-variable combined model (i.e., sex, handgrip strength, shuttle run test, and the Roberton's developmental sequence). Roberton and Konczak[12] used multiple regression analysis to investigate the changing relationship between qualitative movement descriptions of the overarm throw and horizontal ball velocity. The qualitative movement was assessed using the Roberton's developmental sequence, which accounted for 69-85% (adjusted) of the total velocity variance. The components of the development sequences that best predicted ball velocity changed with time. In this study, we also determined that the Roberton's developmental sequence accounted for 64% of the total variance in the ball throwing distance. The development of appropriate overarm throwing technique becomes a factor for increasing the ball throwing distance. The developmental sequence was positively correlated with kinematic variables. Some children, mostly boys, completed the full developmental sequence at an early age (9-10 years). Children should be encouraged to complete their throwing form development by 10 years of age. Childhood is an immature skeleton and muscle strength, it is necessary to increase the throwing ability by the coordination of variety movement components.

Sex differences was also one of the factors involved in the ball throwing distance. Sakurai, et al[23] compared sex differences in the throwing ability of children in three countries (Australia, Japan, and Thailand). They reported that the throwing ability in girls was lower than boys at all ages and in all countries. The recorded ball throwing distances in girls were 51-67% of that in boys. The throwing skills were also lower in girls compared to boys in all three countries. Butterfield et al[24], indicated that boys demonstrated a higher competence in mature throwing patterns compared to girls, and significant sex differences favouring the boys were found. The pre-existing male advantage is accentuated during puberty when numerous body changes occur. The importance in societal factors in creating sex differences has often been proposed. Sex differences might be due to how the society treats boys and girls, which can be influenced by parents, teachers and coaches, rearing factors, cultural expectations, experiential differences, motivations, encouragements, and opportunities for skill development.

Throwing ability of children continue to grow phylogenetically, 64% of the throwing ability can be explained by grade and sex. However, the best model was revealed that developmental sequence, the aerobic capacity, and the grip strength were also important. The role of physical therapist is to help children develop the competencies and beliefs necessary for incorporating regular physical activity into their lives. Children can achieve physical and personal benefits by participating in a well-taught rehabilitation program. Children need increase of the physical activity that improve the grip strength and the stamina as well as the development of their throwing technique.

Conclusion

Researchers have previously determined that throwing ability is influenced by anthropometrical, physical, and developmental factors. In this study, we clarified the intrinsic factors that affect the throwing ability in children.

Our findings provide new insights into the importance of correct developmental parameters in throwing ability. In addition, we determined that improving the throwing sequence and enhancing the grip strength and aerobic capacity are important for improving the overall throwing ability in Japanese children. Future directions of this study include research to identify ways in which children can develop correct throwing sequences through rehabilitation and physical education. Furthermore, the effects of extrinsic factors (e.g., environmental, social, and economic conditions) on the development of throwing ability should also be examined in future studies. Educating throwing techniques is difficult because of complex individual variation. Therefore, it is necessary to consider the most suitable time and effective instruction for the development of throwing ability. Finally, a relationship between developmental change and throwing ability should be evaluated by conducting a longitudinal study.

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